CHAPTER 3: COMPOSITION OF SUBSTANCES AND SOLUTIONS

SOLUTIONS VOCABULARY

- Solvent
- Solute
- Aqueous Solution
- Molarity

MOLARITY

$$\frac{moles\ solute}{volume\ of\ solvent} = M$$

Find the molarity of the solution if 40 g of NaCl is dissolved in 250 mL of water.

CALCULATE THE FORMULA MASS, NUMBER OF MOLES OF MOLECULES, AND NUMBER OF MOLES OF EACH ATOM IN THE COMPOUND

$$16.783\ g\ of\ Mg(NO_2)_2$$

$$24.305\frac{g}{mol} + \left(2 \times 14.007\frac{g}{mol}\right) + \left(4 \times 15.999\frac{g}{mol}\right) = 116.279\frac{g}{mol}$$

$$16.783\ g\ \div 116.279\frac{g}{mol} = 0.14433\ moles\ of\ Mg(NO_2)_2$$

$$0.14433\ moles\ Mg(NO_2)_2\ \left(\frac{1\ mole\ Mg}{1\ mole\ Mg(NO_2)_2}\right) = 0.14433\ \text{moles Mg}$$

$$0.14433\ moles\ Mg(NO_2)_2\ \left(\frac{4\ moles\ O}{1\ mole\ Mg(NO_2)_2}\right) = 0.57733\ moles\ O$$

$$0.14433\ moles\ Mg(NO_2)_2\ \left(\frac{2\ moles\ N}{1\ mole\ Mg(NO_2)_2}\right) = 0.28866\ \text{moles N}$$

FINDING THE EMPIRICAL FORMULA

Nylon-6 contains 63.68% C, 12.38% N and 9.80% H and 14.14% O by mass.

What is the empirical formula for Nylon-6?

1. Assume you have 100g of compound. Find the number of moles of each type of atom.

$$63.68\ g\ C\left(\frac{1\ mole\ C}{12.011\ g}\right) = 5.301\ moles\ C$$

$$9.80\ g\ H\left(\frac{1\ mole\ H}{1.008\ g}\right) = 9.72\ moles\ H$$

$$14.14\ g\ O\left(\frac{1\ mole\ O}{15.999\ g}\right) = 0.8838\ moles\ O$$

$$12.38\ g\ N\left(\frac{1\ mole\ N}{14.007\ g}\right) = 0.8838\ moles\ N$$

2. Divide each value by the fewest number of moles.

$$\frac{5.301}{0.8838} = 5.998 \approx 6$$

$$\frac{9.72}{0.8838} = 10.998 \approx 11$$

FINDING THE MOLECULAR FORMULA

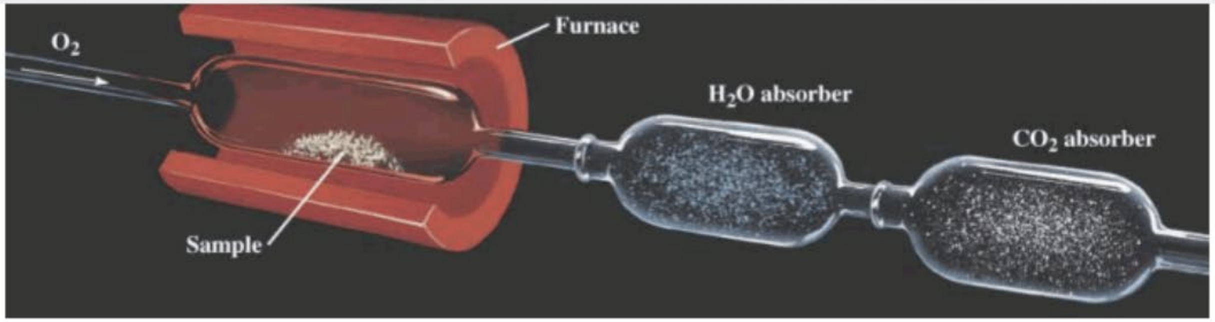
Nylon-6 contains 63.68% C, 12.38% N and 9.80% H and 14.14% O by mass. What is the empirical formula for Nylon-6?

3. Determine the lowest whole number ratio of atoms to find the empirical formula.

$$C:H:N:O \rightarrow 6:11:1:1$$

$$C_6H_{11}NO$$

FINDING THE MOLECULAR FORMULA



A **3.270** gram sample of an organic compound containing C, H and O is analyzed by combustion analysis and **4.793** grams of CO_2 and **1.962** grams of H_2O are produced.

In a separate experiment, the molar mass is found to be **60.05** g/mol. Determine the empirical formula and the molecular formula of the organic compound.

Enter the elements in the order C, H, O

empirical formula = ______

molecular formula = ______

FINDING THE MASS OF SOLUTE GIVEN MOLARITY

How many grams of NaOH must be used to prepare 200.0 mL of a 3.00 M solution?

$$200.0\ mL\left(\frac{3.00\ mol}{L}\right)\left(\frac{1\ L}{1000\ mL}\right)\left(\frac{39.997\ g\ NaOH}{mol}\right) = 24.0\ g\ of\ NaOH$$

FINDING THE NUMBER OF MOLES GIVEN MOLARITY

- How many moles of KCL are in a 45.0 mL of a 1.50 M solution?

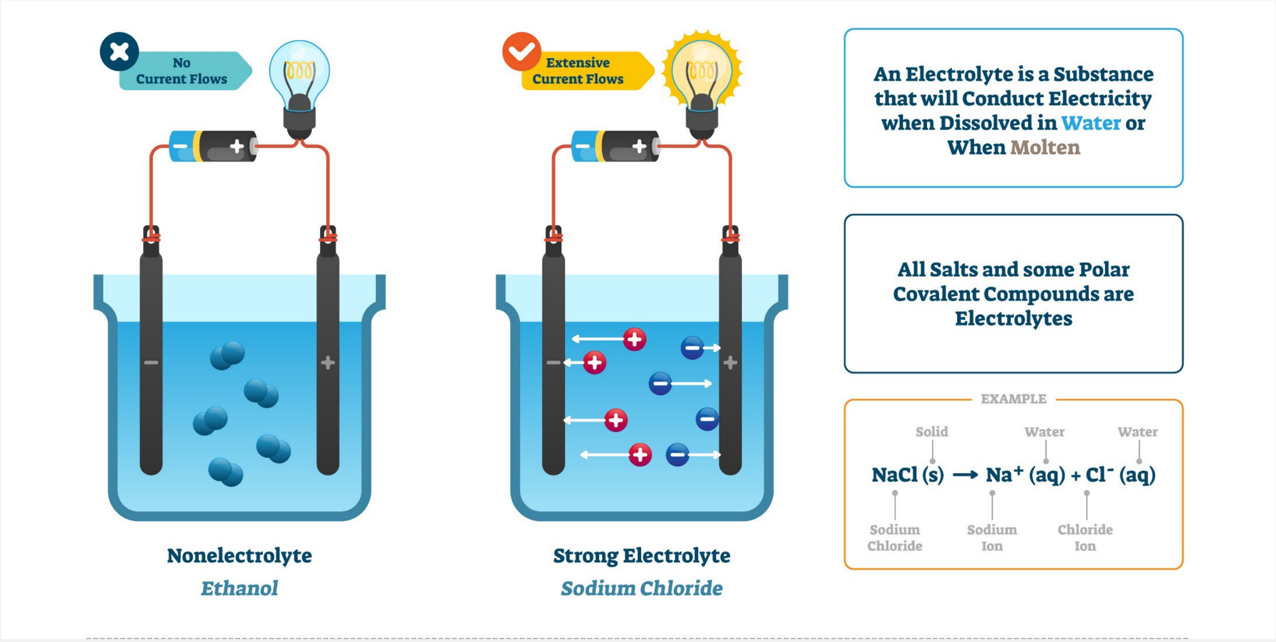
  - $45.0\ mL\left(\frac{1\ L}{1000\ mL}\right)\left(\frac{1.50\ moles}{L}\right) = 0.0675\ moles\ of\ KCl$

- What volume of this solution contains 0.750 moles of KCl?

  - $0.750\ moles\ KCl\ \left(\frac{1\ L}{1.50\ moles}\right) = 0.500\ L$

ELECTROLYTES

- Electrolytes dissociate into ions in water. Electrolyte solutions conduct electricity
  - Examples: ionic compounds, strong acids, strong bases
    - $Mg_3(PO_4)_{2(aq)} \rightarrow 3\, Mg^{2+}_{(aq)} + 2\, PO_4^{3-}{}_{(aq)}$
- Non-electrolytes do not dissociate
  - Examples: Sugar, methanol, caffeine
- Weak electrolytes partially dissociate
  - Examples: Weak acids and weak base
    - $CH_3COOH_{(aq)} \leftrightarrow H^+_{(aq)} + CH_3COO^-_{(aq)}$



CONCENTRATION OF IONS

Find the concentration of ions when 10.00 g of calcium chloride is dissolved in 200.0 mL of water.

$$\frac{10.00\ g\ CaCl_2}{200.0\ mL}\left(\frac{1000\ mL}{1\ L}\right)\left(\frac{1\ mole\ CaCl_2}{100.98\ g}\right)\left(\frac{3\ moles\ of\ ions}{1\ mole\ CaCl_2}\right) = 1.485\ \text{M of ions}$$

DILUTION

Adding water to a solution to lower the concentration

Changing the volume but not the number of moles

$$M_1V_1 = M_2V_2$$

$$\left(\frac{mol}{L}\right)(L) = \left(\frac{mol}{L}\right)(L)$$

What volume of 10.0 M sulfuric acid is needed to make 500.0 mL of a 0.75 M solution.

$$(10.0\ M)V_1 = (0.75\ M)(500.0\ mL)$$
$$V_1 = 37.5\ mL$$

MASS PERCENT AND VOLUME PERCENT

- Units of concentration
- Mass percent: percent by mass of a component in a solution
  - $mass\ percent = \frac{mass\ of\ component}{mass\ of\ solution} \times 100\%$
- Volume percent: percent by volume of a component of the solution
  - $volume\ percent = \frac{vol\ of\ component}{vol\ of\ solution} \times 100\%$

EXAMPLE: MASS PERCENT

- What is the mass of acetic acid in 200.0 mL of a 5% (m/m) acidic acid solution. Acetic acid has a density of 1.02 g/mL

- $200.0\ mL\ \left(\frac{1.02\ g\ of\ solution}{mL}\right)\left(\frac{5\ g\ of\ acetic\ acid}{100\ g\ of\ solution}\right) = 10.2\ g\ of\ acetic\ acid$

EXAMPLE: MASS PERCENT

What mass of both water and potassium chloride is needed to make a 250.0 g solution of a 5.00% m/m solution?

$$250.0\ g\ \times 5\% = 12.5\ g$$

$$12.5\ g\ \text{of potassium chloride}$$

$$237.5\ g\ of\ water$$

PPM AND PPB

- "Parts per Million"
  - $ppm = \frac{mass\ of\ component}{total\ mass} \times 10^6\ ppm$
- "Parts per Billion"
  - $ppb = \frac{mass\ of\ component}{total\ mass} \times 10^9\ ppb$

Percent is like "parts per hundred"

$\% = \frac{mass\ of\ solute}{mass\ of\ solution} \times 10^2\ \%$

PPM EXAMPLE

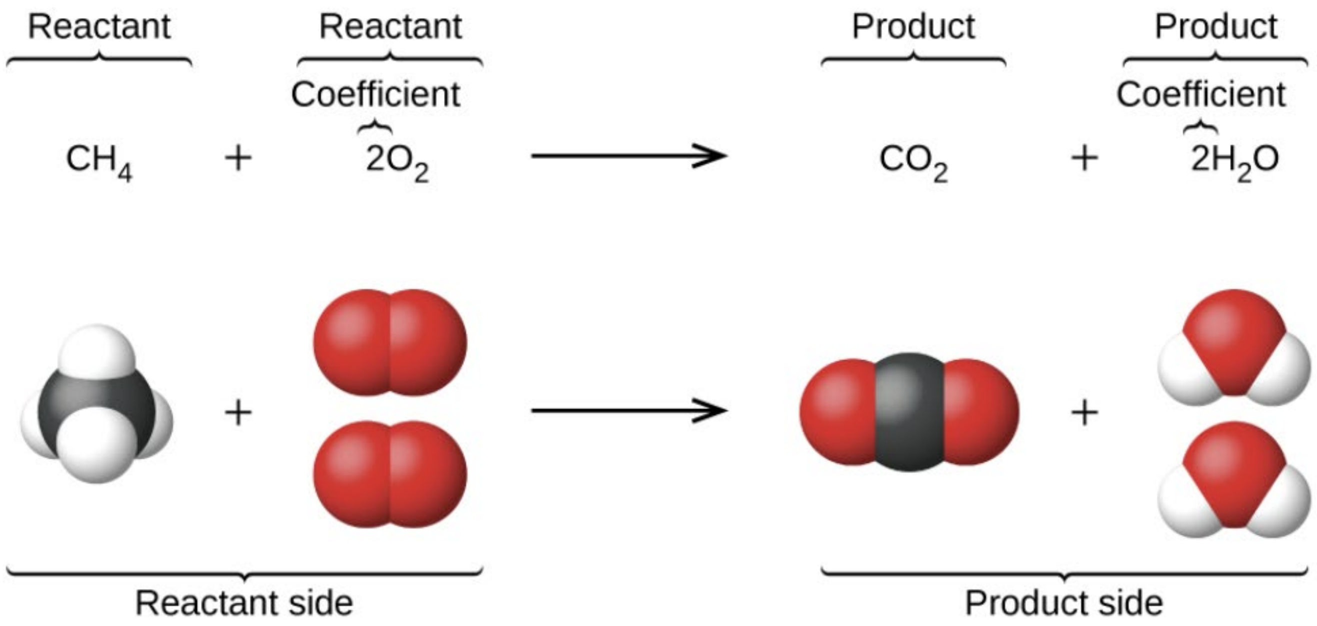
The EPA monitors lead in tap water to ensure that it does not exceed 15 ppb. What is this concentration in ppm? At this concentration, what mass of lead in micrograms would be contained in a typical glass of water (300. mL)? The density of water is 1.00 g/mL.

$$15\ ppb\ \left(\frac{10^6\ ppm}{10^9 ppb}\right) = 0.015\ ppm$$

$$300.\ mL\ \left(\frac{1.00\ g}{1\ mL}\right)\left(\frac{10^6\ \mu g}{1\ g}\right)\left(\frac{0.015\ parts}{10^6}\right) = 4.5 \mu g$$

CHAPTER 4

WRITING AND BALANCING CHEMICAL EQUATIONS



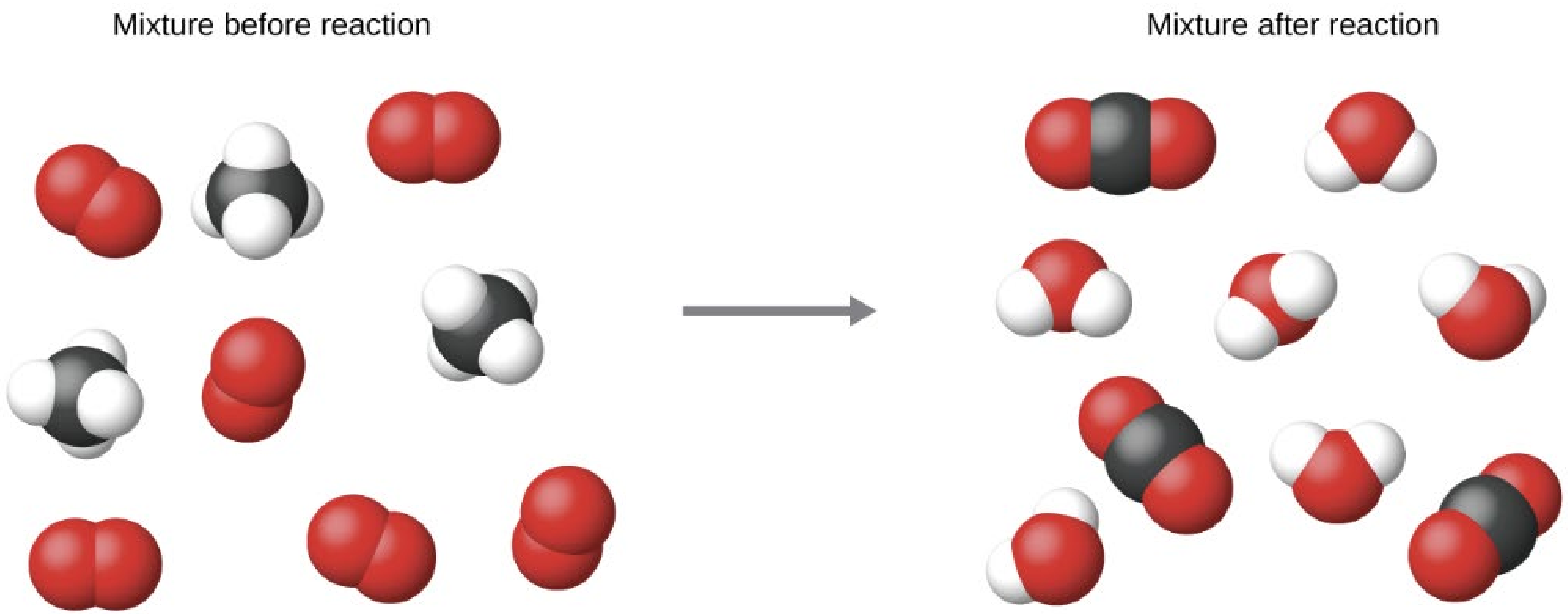


Figure 4.3 Regardless of the absolute numbers of molecules involved, the ratios between numbers of molecules of each species that react (the reactants) and molecules of each species that form (the products) are the same and are given by the chemical reaction equation.

BALANCING CHEMICAL EQUATIONS EXAMPLE

Balance the equations

$$\_\_\_\_\_N_{2(g)} + \_\_\_\_\_H_{2(g)} \rightarrow \_\_\_\_\_NH_{3(g)}$$

$$\_\_\_\_\_Pb_{(s)} + \_\_\_\_\mathrm{H_2O_{(l)}} + \_\_\_\_\_O_{2(g)} \rightarrow \_\_\_Pb(OH)_{2(s)}$$

$$\_\_\_\_Al_2(SO_4)_{3(aq)} + \_\_\_\_Ca(OH)_{2_{(aq)}} \rightarrow \_\_\_\_\mathrm{Al(OH)_{3(s)}} + \_\_\_\_\mathrm{CaSO_{4(aq)}}$$

AQUEOUS IONIC EQUATIONS

Molecular Equation: Reactants and Products written as undissociated compounds

$$Na_2CO_{3(aq)} + CaCl_{2(aq)} \rightarrow 2\ NaCl_{(aq)} + CaCO_{3(s)}$$

Total Ionic Equation: All aqueous species dissociate into their respective ions

$$2\ Na^+_{(aq)} + CO^-_{3(aq)} + Ca^{2+}_{(aq)} + 2Cl^-_{(aq)} \rightarrow 2\ Na^+_{(aq)} + 2Cl^-_{(aq)} + CaCO_{3(s)}$$

Net Ionic Equation: Ions that remain aqueous are not included.

$$CO^-_{3(aq)} + Ca^{2+}_{(aq)} \rightarrow CaCO_{3(s)}$$

TYPES OF CHEMICAL REACTIONS

Precipitation Reaction

Formation of a solid precipitate

Acid-Base Reaction

Reaction between an acid and a base

Redox Reaction

Reaction that involves the transfer of electrons

PRECIPITATION AND SOLUBILITY RULES

- Precipitates form when a pair of ions in solution form an insoluble compound
- Compounds are soluble when the energy associated with the ionic bond is less than the energy associated with hydration

SOLUBILITY RULES

Soluble

1. All common compounds of Group 1A(1) ions (Li^+, Na^+, K^+...) and ammonium ions ($NH4^+$)

2. All common nitrates (NO_3^-), acetates ($CH_3CO_2^-$) and most perchlorates (ClO_4^-)

3. All common chlorides (Cl^-), bromides (Br^-) and iodides (I^-); *except* those of Ag^+, Pb^{2+}, Cu^+ and Hg_2^{2+}. All common fluorides (F^-) are soluble; *except* for Pb^{2+} & Group2A(2)

4. All common sulfates (SO_4^{2-}); *except* Ca^{2+}, Sr^{2+}, Ba^{2+}, Ag^+ & Pb^{2+}

Insoluble

1) All common metal hydroxides are **insoluble**; *except* those of Group 1A(1) and the larger members of Group 2A(2) - beginning with Ca^{2+}.

2) All common carbonates (CO_3^{2-}), phosphates (PO_4^{3-}) and chromates (CrO_4^{2-}) are **insoluble**; *except* those from Group 1A(1) and ammonium (NH_4^+).

3) All common sulfides (S^{2-}) are **insoluble**; *except* those of Groups 1A(1), 2(A)2 and NH_4^+.

SOLUBILITY RULES

SOLUBILITY EXAMPLE

- Write the molecular, ionic and net ionic equation for the reaction of lead (II) nitrate with potassium iodide.

$$Pb(NO_3)_{2(?)} + 2\ KI_{(?)} \rightarrow 2\ KNO_{3(?)} + PbI_{2(?)}$$

$$Pb(NO_3)_{2(aq)} + 2\ KI_{(aq)} \rightarrow 2\ KNO_{3(aq)} + PbI_{2(s)}$$

$$Pb^{+2}_{(aq)} + 2\ NO_3^-{}_{(aq)} + 2\ K^+_{(aq)} + 2\ I^-_{(aq)} \rightarrow 2\ K^+_{(aq)} + 2\ NO_3^-{}_{(aq)} + PbI_{2(s)}$$

$$Pb^{+2}_{(aq)} + 2\ I^-_{(aq)} \rightarrow PbI_{2(s)}$$

SOLUBILITY EXAMPLE 2

Write the molecular, total ionic and net ionic equations for the reaction of potassium nitrate with silver acetate.

$$KNO_{3(?)} + AgCH_3COO_{(?)} \rightarrow AgNO_{3(?)} + KCH_3COO_{(?)}$$

$$KNO_{3(aq)} + AgCH_3COO_{(aq)} \rightarrow AgNO_{3(aq)} + KCH_3COO_{(aq)}$$

$$K^+_{(aq)} + NO^-_{3(aq)} + Ag^+_{(aq)} + CH_3COO^-_{(aq)} \rightarrow Ag^+_{(aq)} + NO^-_{3(aq)} + K^+_{(aq)} + CH_3COO^-_{(aq)}$$

All species are aqueous = NO REACTION